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MANUFACTURING METHODS AND TECHNOLOGY FOR HERMETICALLY SEALED LI--ETC(U)
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TECHNICAL REPORT 0042-Q-03 APRIL, 1977

MANUFACTURING METHODS AND TECHNOLOGY FOR HERMETICALLY SEALED LITHIUM SO_2 CELL BATTERIES

THIRD QUARTERLY REPORT

1 JANUARY 1977 TO 31 MARCH 1977

CONTRACT NO. DAAB07-76-C-0042

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Prepared by

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For

U. S. ARMY ELECTRONICS COMMAND, Fort Monmouth, N. J. 07703

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Effort is continuing on the MM&T program to establish the fabrication techniques and requirements to meet hardware production levels as specified in the subject contract. Hermetic cell samples are presently being fabricated and tested under the required thermal discharge profiles to demonstrate the feasibility of each cell design. Prototype hermetic battery models are being constructed to verify conformance to all dimensional and weight specifications. Such models will aid in the finalization → over

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of complete drawing packages for each of the battery types. These drawings will define all required cell/battery components, sub-assemblies and process specifications and will be accompanied by a detailed bill of material to insure proper configuration control.

The first prototype core winder has been installed at PCI and is presently undergoing evaluation and modifications as required. Initial trials of the continuous cathode machine have been completed and fabrication of mixing/transfer vessels is currently in progress. Equipment design and fabrication of hermetic closure, anode manufacture and electrolyte preparation and dispensing equipment is presently underway to permit subsequent integration within an operational production line. Interface with automated equipment manufacturers continue in order to assemble and evaluate the required equipment within the time frame of the PERT/TIME Network.

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ABSTRACT

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PURPOSE

The basic objectives of this program are to:

a) establish the producibility of the specified hermetically sealed lithium cells and batteries by mass production techniques and facilities;

b) establish and improve quality control surveillance and inspection;

c) initiate process improvements to minimize overall fabrication costs and time.

The program consists of six (6) primary components:

- Battery and Cell Design
- Electrolyte Preparation and Dispensing System
- Core Winding Machine Design
- Cathode Manufacture
- Anode Manufacture
- Welding Equipment Design

Evaluation of the above independent tasks will be conducted in parallel to permit subsequent integration within an operational manufacturing process.

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I. INTRODUCTION

The Manufacturing Methods and Technology (MM&T) Project No. 2759371 to Establish Automatic Electrode Production for Lithium Hermetic Cells requires the establishment of production techniques for hermetic lithium cell components, cells and batteries to meet production levels delineated in the contract. Specifically, the following hermetic batteries will be manufactured utilizing the automatic electrode processes established under this program:

BA-5590 ( )/U	BA-5574 ( )/U
BA-5585 ( )/U	BA-5841 ( )/U
BA-5090 ( )/U	BA-5100 ( )/U
BA-5842 ( )/U	BA-5567 ( )/U
BA-5568 ( )/U	BA-5598 ( )/U

The production engineering goals of this program are to perform the necessary design, development, engineering, fabrication of special tooling and construction of test facilities and limited production equipment to obtain confirmatory sample approval; and to establish a pilot line and pilot run for the purpose of demonstrating a manufacturing process.

As a result, Power Conversion, Inc. will establish a Pilot Line and demonstrate the capability of this line with at least 20% of the Pilot Run units. The rates to be met are:

5,000 "D" Type Cells in an eight-hour day.

2,500 cells other than "D" Type* cells in an eight-hour day.

*Other than "D" type cells are those cells to be utilized in the fabrication of the deliverable batteries.

II. PROGRAM EVALUATION & REVIEW TECHNIQUE

The overall program objectives have proceeded in accordance with the PERT Chart as shown in Figure 1. This chart reflects the present program status of each task with respect to meeting the required contract target dates.

Several problem areas have been resolved during this quarterly period with respect to the following:

- Arc Welding - Thermal damage of the cell insular/separator has occurred during arc welding of the cell periphery. This condition has been corrected by the use of adequate lower/upper heat sinks to remove excess heat and by altering the weld parameters. Such changes have also been implemented on the automated welding equipment to avoid this problem.

- Resistance Welding - Resistance welding of small diameter cells (< 15/16 inch diameter) has been unsatisfactory due to a heat unbalance at the weld surface interface. This condition is presently being corrected by modification of the can/top structure and the weld electrodes.

- BA-5567/BA-5568 Cell Design - Difficulty in achieving the dimensional and performance requirements of these cells has been encountered. An alternative dual top construction is presently being evaluated as a means of minimizing these assembly problems.

- BA-5100/BA-5090 Vent Design - The side wall vent design for these cells requires modification due to deformation of the can periphery during the coining operation. Tooling is presently being revised to correct this condition and additional vent evaluation tests will be performed to demonstrate proper vent operation.

Priorities have been restructured in order to implement the necessary corrective action and maintain the con-

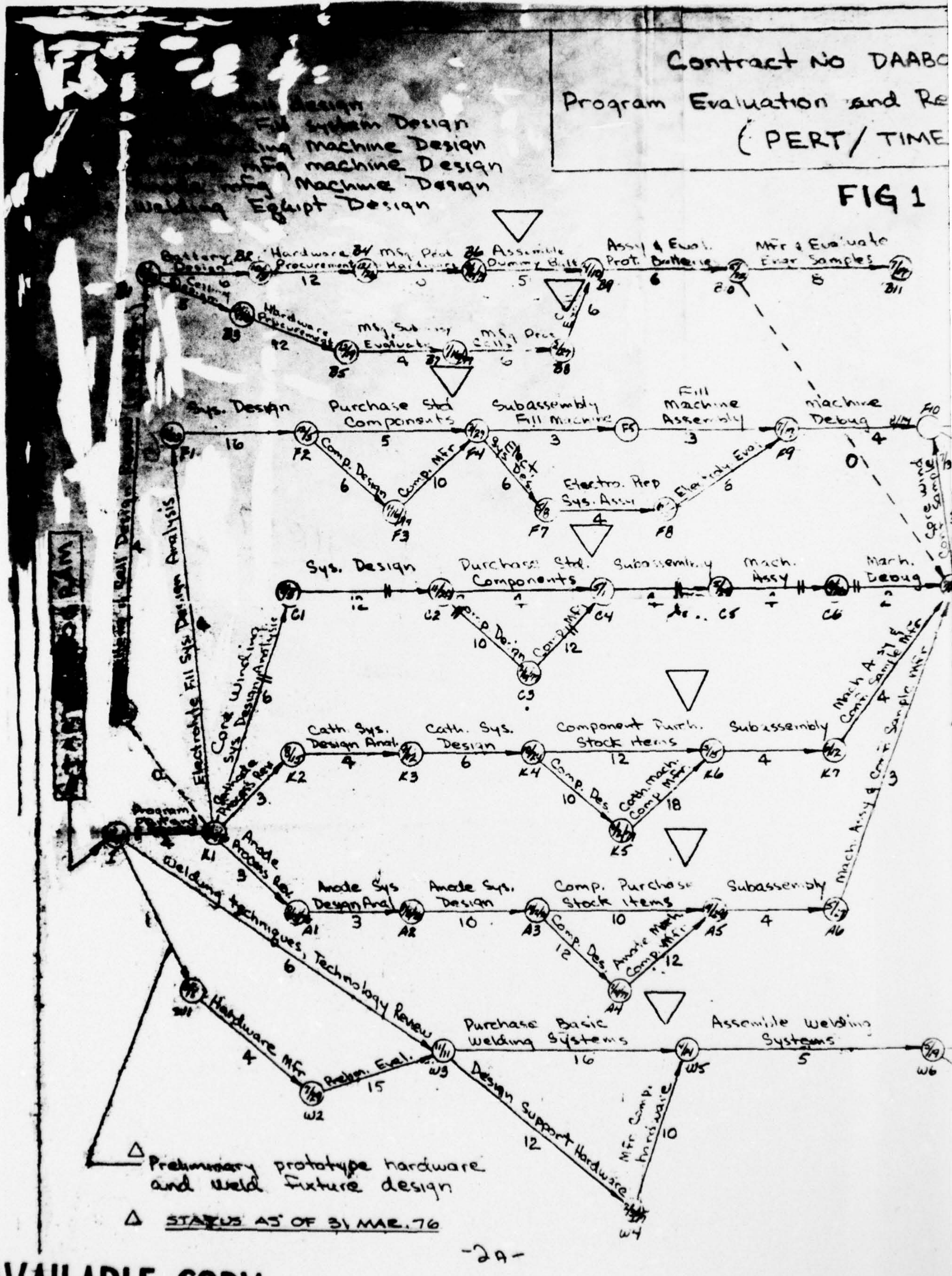

FIG 1

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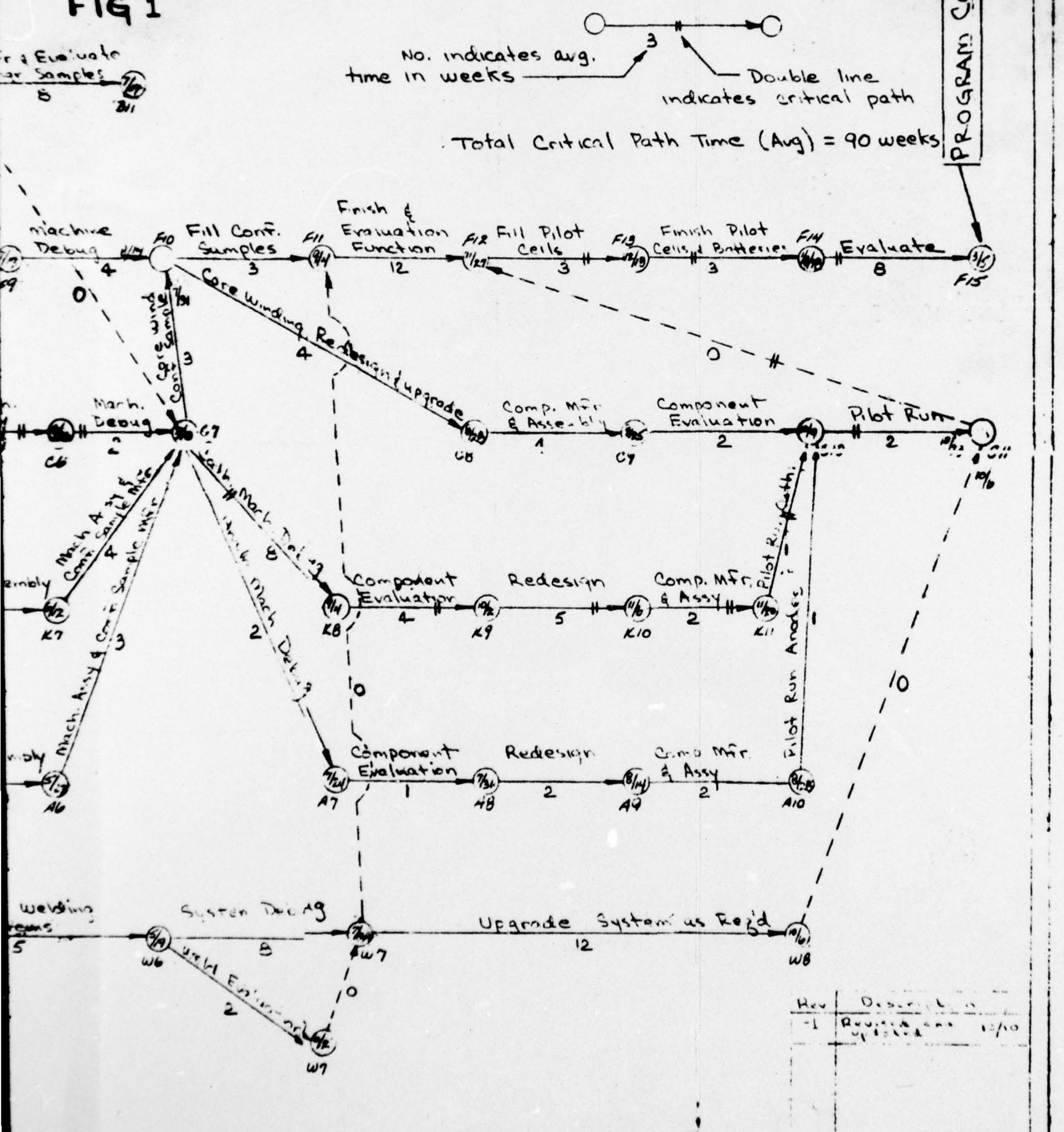
...tion and Review Technique

...PERT/TIME) CLIN 0002

Power Conversion Inc
Mt Vernon New York
July 1976

FIG 1



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tract target dates. Periodic review of the PERT/TIME Network will be continued during the next quarterly period in order to identify and define any additional problem areas as they occur. Such action will permit timely corrective action and will avoid serious delays during cell/battery assembly and equipment manufacture.

III. CELL AND BATTERY DESIGN

A. CELL DESIGN

The specific electrode configurations of some cell designs have been revised as a result of electrical discharge performance data, theoretical internal volume analysis and re-evaluation of current density levels. The revised cell electrode characteristics are summarized in Table 1.

B. CELL PROTOTYPE FABRICATION

Initial hermetic cell prototypes are presently being constructed to verify proper dimensional conformance and electrical performance under the required thermal discharge profiles. Difficulty has been encountered in the following areas:

- BA-5100/BA-5090 Cells - Coining of the side wall vent has resulted in excessive deformation of the can periphery at the open end due to the short overall length of these cells. Modifications are presently being made to the vent tooling to decrease the length of the scored section and provide additional can support to minimize such deformation.

- BA-5574/BA-5841/BA-5090 Cells - Difficulty has been encountered during peripheral welding using the plasma arc or arc welding process due to thermal cracking of the glass/metal seal. Use of various configured heat sinks has failed to correct this condition. Additional effort is being placed to construct such cells using the resistance weld process.

- BA-5567/5568 Cells - Difficulty has been encountered with the winding of the electrodes due to improper registration of the electrode/separator. An alternative design as shown in Figure 2 is presently being considered to correct this registration problem and increase internal cell volume. The core will be wound outside the inner top structure which will maximize electrode width without significantly comprimising electrode surface area. Feasibility of resistance welding the inner top structure will be determined during the next reporting period.

Preliminary discharge tests have been performed on the following hermetic cell prototypes:

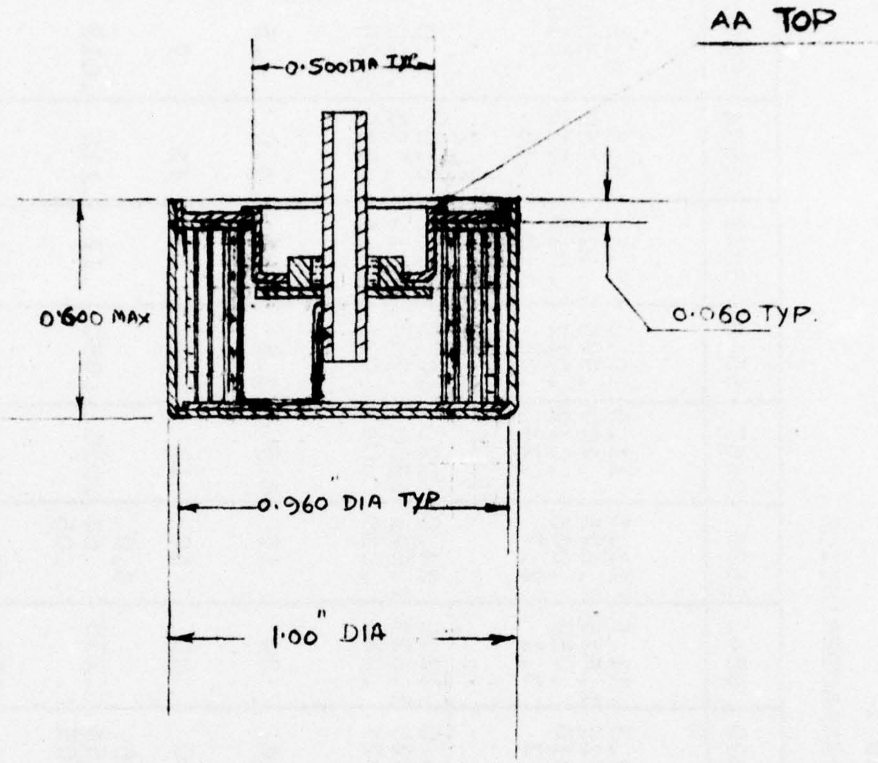
BA-5842 Cell

Discharge Profile: 175 ma constant current

TABLE 1

CELL ELECTRODE CHARACTERISTICS

BATTERY TYPE	5598	5100	5590	5842	5585	5567	5568	5841	5574	5090
ANODE										
Length	23.5	23.5	23.5	11.5	23.5	11.5	10.0	5.5	5.5	4.5
Width	1.375	.562	1.625	1.625	1.625	.200	.200	2.125	.750	.500
Thickness	.012	.012	.010	.019	.008	.012	.012	.010	.010	.010
Weight (gm)	3.4	1.4	3.3	3.1	2.7	.24	.21	1.0	.36	.2
CATHODE										
Length	24.0	24.0	24.0	12.0	24.0	12.0	10.5	6.0	6.0	5.0
Width	1.375	.562	1.625	1.625	1.625	.200	.200	2.125	.750	.500
Thickness	.033	.033	.025	.040	.020	.033	.033	.025	.025	.025
ELECTROLYTE										
Weight (gm)	36.5	20	34	34	15	4.5	3.5	8.0	4.0	2.5
CELL WEIGHT (gm)	87	37	80	80	58	12	12	23	12	7
CURRENT REQUIREMENTS (amps)	.95 .048	.093	3.0 .64 .05	.175	3.0 .64 .05	.056	.090	.12	.115	.013
CATHODE SURFACE AREA (cm^2)	426	174	503	252	503	31	27	165	58	32
CURRENT DENSITY LEVEL (ma/cm^2)	2.23 .11	.53	6.0 1.3 .10	.69	6.0 1.3 .10	1.81	3.33	.73	1.98	.41



BA-5567 CELL DESIGN

FIGURE 2

Discharge Temperature (°F)	Required Service @ 2.0 volts (hours)	Actual Service @ 2.0 volts (hours)
+70	48	51.2
-20	24	32.2
+130	42	46.0

BA-5590 Cell

Discharge Profile: 0.8 ohm @ 100ms every minute
3.9 ohm @ 1 minute
56.0 ohm @ 19 minutes

Discharge Temperature (°F)	Required Service @ 2.0 volts (hours)	Actual Service @ 2.0 volts (hours)
+70	48	58.5
-20	24	28.9

BA-5598 Cell

Discharge Profile: 2.84 ohm @ 2 minutes
58.2 ohm @ 18 minutes

Discharge Temperature (°F)	Required Service @ 2.0 volts (hours)	Actual Service @ 2.0 volts (hours)
+130	50	56.9
+70	50	59.5
-20	35	39.3

C. CELL SAFETY

Effort during this quarterly period has been directed towards the continued evaluation and design refinement of the coined side wall vent structure which is being contemplated for use on all cells required under this program. The safety mechanism as illustrated in Figure 3 essentially consists of a coined cross section located in the can wall and parallel to the center line. The coined structure is rolled radially inward during fabrication which accomplishes the following:

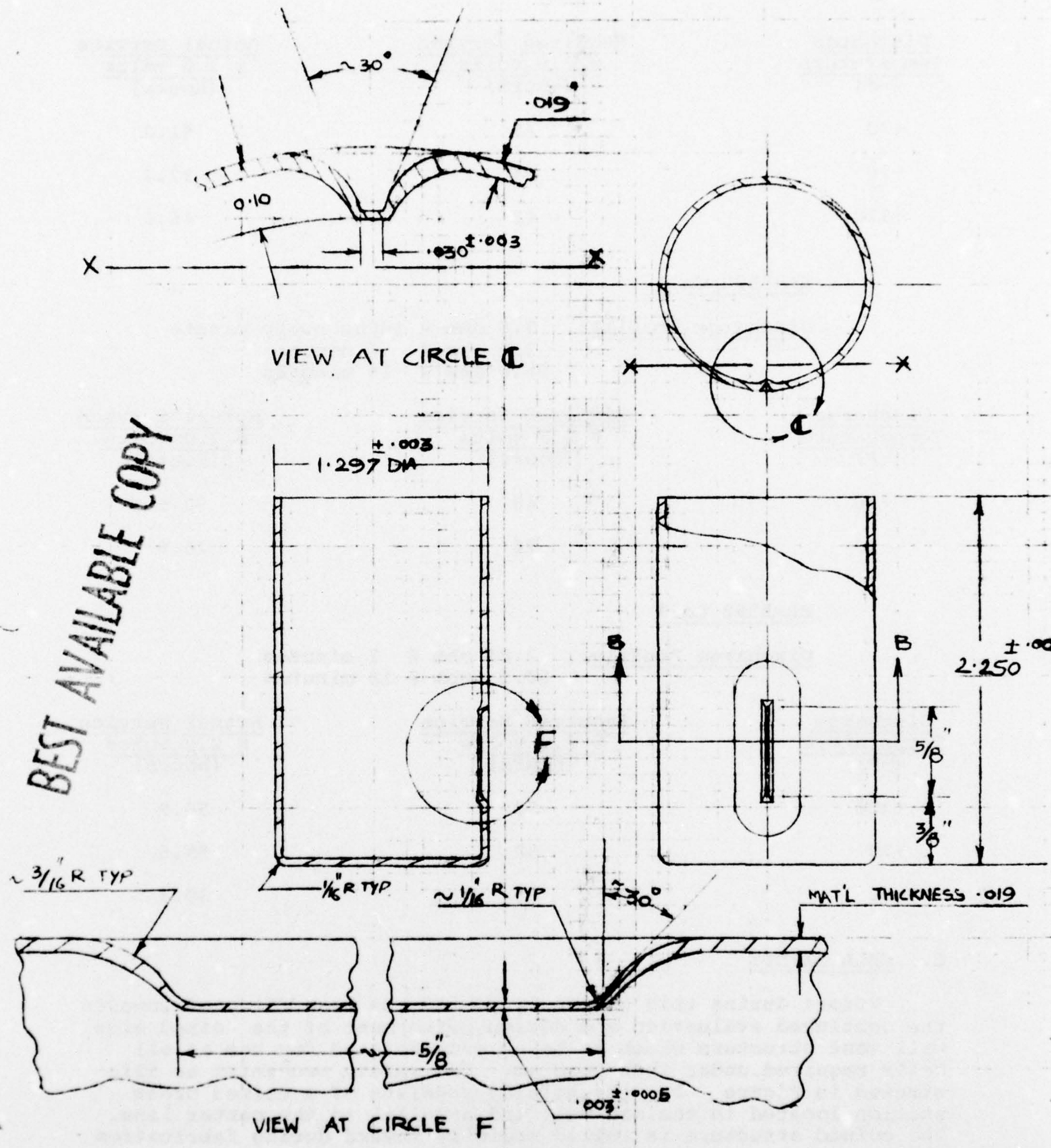


FIGURE 3

SAFETY VENT MECHANISM

- Minimizes the bulging of the can outer diameter to conform to the required envelope dimensions during all required thermal environments.

- Provides a pivot configuration which minimizes tensile loading of the coined surface during normal cell storage and operating environments. The flexure joint is designed to invert at approximately 200 - 210 °F at which point, the coined section is subjected to direct tensile loading due to the electrolyte vapor pressure within the cell. Such action provides greater control and reproducibility of the venting characteristics and permits a graduated release of electrolyte upon venting.

- Provides protection and isolation of the vent structure during cell/battery assembly and handling to prevent accidental vent rupture or damage.

The cans are initially annealed in a reducing atmosphere at 1750 - 1800 °F for 4.5 minutes to provide uniform material hardness throughout the can. Hardness uniformity is particularly important to control the coined section thickness during the subsequent forming operations. Evaluations are presently underway to quantitatively determine the effects of post annealing of the coined section on vent performance and reproducibility.

Preliminary abuse tests have been performed to demonstrate the performance, reliability and reproducibility of the vent during exposure to short circuit, high current discharge, hot plate tests, elevated thermal storage tests, hydraulic pressurization tests, etc. Such abuse tests have shown reproducible cell venting at a stabilized temperature of 220 - 240 °F as shown in Tables 2 and 3 .

D. BATTERY PROTOTYPE FABRICATION

Prototype hermetic battery models are presently being constructed to verify conformance to all dimensional and weight specifications. Such models will aid in the finalization of complete drawing packages for each of the cell/battery types. These drawings which are presently in progress will define all required components, sub-assemblies and process specifications and will be accompanied by a detailed bill of material to insure proper configuration control.

Difficulty has been encountered with the following battery types:

- BA-5100 - The CRS case thickness must not exceed .010 inch in order to conform to the specified battery outline dimensions. PCI is presently investigating various sources to fabricate such cases. In addition, PCI is requesting a change in the jacket material to PVC or equivalent to permit conformance to the required battery envelope and minimize case insulation problems.

TABLE 2

ABUSE TEST DATA SUMMARY

Cell Type: 1500-2000
Diameter: 1¼ inch
Height: 2.0 inch

Test Description	Cell Quantity Tested	Vent Temp Range (°F)	Avg. Vent (Sec)	Vent Pressure Range (psi)
High Temp. Exposure. 2°F/minute	10	220-236	-	-
Short Circuit Test. .01 ohm	15	175-200	135	-
Hot Plate Test.	10	210-240	300	-
Hydraulic Pressurization	10	-	-	400-435

Cell Type: 660-S
Diameter: 15/16 inch
Height: 2.0 inch

Test Description	Cell Quantity Tested	Vent Temp Range (°F)	Avg. Vent Time (Sec)	Vent Pressure Range (psi)
High Temp. Exposure. 2°F/minute	10	225-240	-	-
Short Circuit Test. .01 ohm	15	180-206	186	-
Hot Plate Test	10	215-245	350	-
Hydraulic Pressurization	10	-	-	415-450

TABLE 3

HIGH TEMPERATURE EXPOSURE DATA

The High Temperature Exposure Test is considered to be the most accurate means of determining the actual cell venting temperature since the rate of temperature increase ($2^{O}F$/minute) is carefully controlled and permits complete and gradual thermal stabilization of the cell and its environment. The following summarizes the actual venting temperatures of two cell types during the above test.

	Vent Temperature (^{O}F)		Vent Temperature (^{O}F)
S/N	Model 1500-2000	S/N	Model 660-S
01	225	01	240
02	236	02	238
03	235	03	240
04	230	04	228
05	230	05	235
06	220	06	225
07	235	07	240
08	223	08	235
09	220	09	235
10	225	10	227

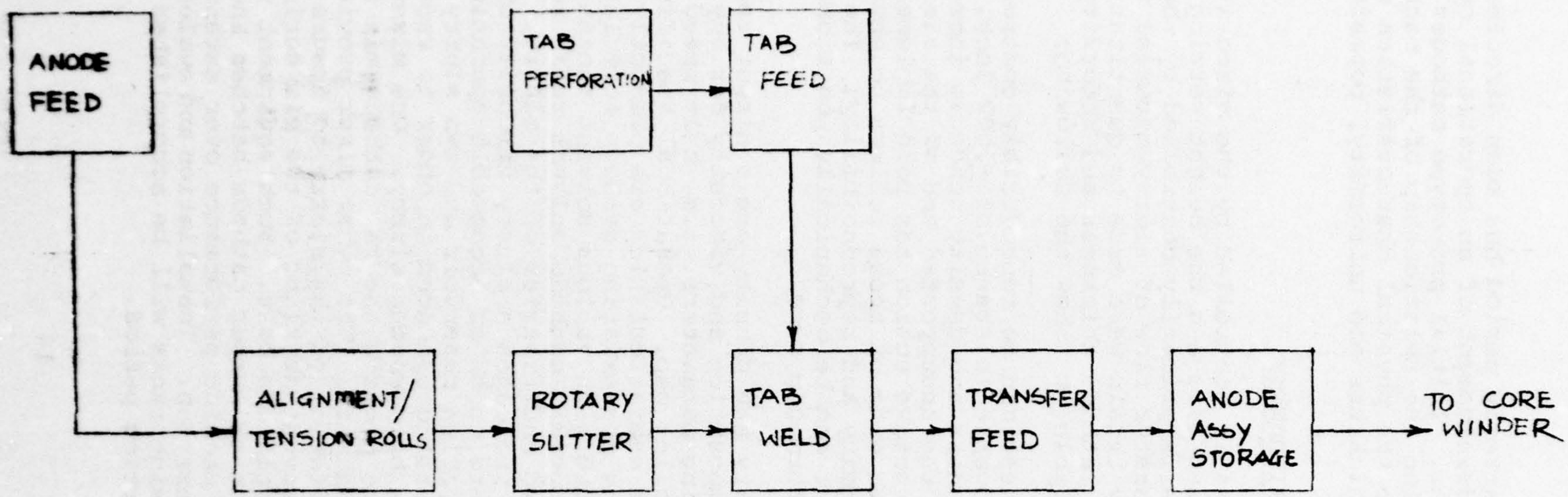
IV. ANODE FABRICATION

Effort has been directed during this quarterly period to determine the feasibility of integrating the anode tab welding and lithium rotary slitter with a transfer feed mechanism which would mate with the input of the core winder. Difficulty has been encountered during manual handling, transfer and storage of the anode due to the extreme ductility and adherence characteristics of lithium foil. Physical distortion of the anode results in significant delays during subsequent electrode loading within the core winder feed station (See Section VI.).

PCI is presently evaluating a semi-automatic rolling/feeding mechanism to insure electrode flatness and minimize manual material handling. This mechanism would sequentially accept pre-cut tabbed anodes and automatically transfer the assembly to a storage station. Orientation of the tabbed anode assembly would be maintained to facilitate transfer to the core winder.

The tabbed anodes must also be properly stored to prevent distortion of the lithium until its subsequent transfer to the core winder. The proposed anode storage station would consist of a series of loading magazines which would accept the transferred anodes. Physical separation of the anode structures would be accomplished by the use of polymeric separator plates which will maintain anode alignment and prevent contact.

A schematic of the proposed lithium slitter/tab welding system design is shown in Figure 4 .



ANODE FABRICATION PROCESS

FIGURE 4

V. CATHODE FABRICATION

Work during this quarterly period has been directed towards evaluation and continued development of an operational continuous cathode fabrication machine. Initial prototype cathodes have been fabricated to determine the relationship of the machine parameters with respect to the physical characteristics of the cathode, namely cathode thickness and uniformity, porosity and density.

CATHODE THICKNESS/UNIFORMITY

Cathode thickness is controlled by the viscosity of the slurry, belt speed, feed rate and the height setting of the sizing rollers. Feed rate is primarily controlled by the blade gap which controls the transfer flow of slurry material to the belt. Several preliminary trials were made to quantitatively measure the variations in cathode thickness and unformity. The results as summarized in Table 4 show the following:

- Cathode thickness can be reproducibly controlled within an allowable tolerance of $\pm$.002 inch. Material thickness and density tends to increase as it approaches the unsupported end of the sizing rollers. Corrective action has been implemented to support both ends of these rollers to obtain greater uniformity and reproducibility. The support adjustment can be mechanically positioned to achieve a uniform gap size.

- Cathode porosity and density are a direct result of the slurry composition and viscosity for any fixed set of operating parameters, i.e. belt speed, blade gap, sizing roller gap. Operational specifications defining these characteristics are presently being developed. The pre-existing cathode formulation is being blended with various solvent recipes to establish an optimal cathode/solvent ratio to permit proper feed and transfer of the slurry. Preliminary data indicates a slurry viscosity of 1700-1800 cps appears to be an acceptable operating range. A 30 gallon reservoir and two slurry mixers are presently being procured in order to reproducibly achieve such a homogeneous slurry. One mixer will will be used to prepare the raw cathode mix from the starting ingredients. The other mixer provides a continuous agitation of the slurry to insure homogeneity and prevent settling of the mix during transfer to the continuous belt. Such equipment will permit fabrication of larger cathode batches and permit evaluation of machine performance over extended periods of operation. Installation and evaluation of the slurry mixing tanks will be accomplished during the next reporting period.

TABLE 4

CATHODE FABRICATION EVALUATION

Run # 01
Belt Speed 3 feet/minute
Blade Gap 3/16 inch

Cut Lengths (inch)	Width (inch)	Thickness (inch)	Weight (gms)
24	3½	.026-.029	16.5

Run # 03
Belt Speed 2½ feet/minute
Blade Gap 3/16 inch

Cut Lengths	Width	Thickness
13"	12"	.026-.028

Run # 04
Belt Speed 1 foot/minute
Blade Gap 3/16 inch

Cut Lengths (inch)	Width (inch)	Thickness (inch)	Weight (gms)
12	1 23/32	.035	4.2
12	1 23/32	.033-.035	4.3
12	1 23/32	.033-.035	4.35
12	1 23/32	.033-.035	4.4
12	1 23/32	.033	4.1
12	1 23/32	.035	4.6

Run # 04a
Belt Speed 2½ feet/minute
Blade Gap 3/16 inch

Cut Lengths (inch)	Width (inch)	Thickness (inch)	Weight (gms)
12	1 23/32	.033-.037	4.6
12	1 23/32	.035-.038	4.6
12	1 23/32	.035-.038	4.6
12	1 23/32	.035-.038	4.7
12	1 23/32	.035-.038	4.7
12	1 23/32	.035-.038	4.75

Prototype cathodes were subsequently fabricated into Li/SO_2 cells and were electrically discharged under a 2.66 ohm load at room temperature along with appropriate control samples using cathodes fabricated by the present technique. The results are as follows:

Cell Type	Cathode Run #	Storage History	Service Life 2.0 volts (hrs)	Average Output Voltage (volts)
660-5	01	None	25.2	2.70
660-5	Std.	None	24.75	2.70
550	04	None	7.75	2.70
550	04	16 hrs, 130°F	6.7	2.70
550	Std.	None	6.5	2.70
550	05	None	8.0	2.70
550	05	16 hrs, 130°F	7.7	2.70
550	05	16 hrs, 130°F	7.2	2.70
550	Std.	16 hrs, 130°F	6.25	2.70

Various automatic shearing equipment is presently being investigated to permit precise cutting of the continuous cathode sheets in accordance with the pre-established length/width specifications. Such equipment would be physically located downstream of the cathode drying system.

Transfer of the continuous cathode to this shearing station will be accomplished by a variable speed mechanically driven belt which would insure proper alignment and registration of the cathode. Storage of these slit cathodes will be investigated during the next reporting period. Precautions must be taken to insure proper flatness of the cathode to avoid subsequent loading difficulties within the semi-automatic core winder.

VI. CORE WINDER

The first prototype core winding machine has been installed within the dry room facility at Power Conversion, Inc. A common pneumatic exhaust port has been developed to avoid dry room contamination during machine operation. During this quarterly period, effort has been directed towards machine evaluation with respect to the following sequenced operations:

- Anode/Cathode Loading and Registration
- Separator Feed
- Electrode Transfer
- Core Winding
- Core Removal

All evaluation effort to date has been accomplished using the electrode configuration for the BA-5842 battery, i.e.:

Anode: 11.5 x 1 5/8 x .019 inch

Cathode: 12 x 1 5/8 x .042

Separator: Webril

ANODE/CATHODE LOADING AND REGISTRATION

Difficulty has been encountered during the loading of the anode/cathode structure into the feeder slots of the core winder. This condition is primarily due to insufficient electrode flatness and non-uniform irregularities along the cathode surface.

The physical properties of lithium are such that the lattice structure is inherently weak and, consequently, the anode is easily distorted during the slitting/tabbing operation and during normal material transfer. In addition, the cathode as presently fabricated does not have a com-

pletely uniform surface texture due to the limitations of the present cathode process and localized non-homogeneous blending of the cathode ingredients. Such inconsistencies will be minimized when electrodes are fabricated on the continuous cathode fabrication machine as discussed in Section V .

In order to correct the aforementioned conditions, Power Conversion, Inc. is investigating the use of tapered feeder slits to facilitate loading of the electrodes. In addition, the incorporation of a semi-automatic rolling/ feeding mechanism is presently being considered to insure electrode flatness and minimize material handling. The design concept presently under consideration would consist of a series of rotating rollers which would align and flatten the electrodes and transfer to the feeder slots of the core winder. Various magazine feeders are presently under evaluation to permit quantity loading of the electrodes.

Proper electrode alignment with respect to the separator must also be maintained along the entire electrode length to insure adequate separation between the active electrodes. Alignment is presently accomplished by the operator using a light source which is mounted to the rear of the feeder slots. Feasible alternatives will be investigated during the next reporting period to facilitate electrode alignment and registration.

SEPARATOR FEED

Adjustments are presently being made to regulate the separator tension to avoid machine drag during electrode transfer. Alternative feed spools are under evaluation to permit uniform separator feed along the alignment rollers.

ELECTRODE TRANSFER

Transfer of the electrodes/separator from the load station to the core winding station has been successful. However, surface abrasion of cathode material during the transfer process remains a problem area. This condition is primarily due to the presence of surface irregularities on the cathode. However, as mentioned previously, this

condition should be minimized by the use of cathodes formed on the continuous cathode fabrication equipment. In addition, provisions are being made to equip the transfer rollers with a means of self cleaning to avoid the buildup of contamination.

CORE WINDING

The actual winding of the electrode core (not including electrode loading) has been successfully demonstrated within a cycle time of 3 seconds. Electrode registration at this point is a function of the initial alignment during the loading process. The present "D" cell design allows for a 1/8 inch wide tolerance on each end of the electrodes over its entire length.

CORE REMOVAL

Upon completion of the core wind cycle, the split mandrel retracts allowing manual removal of the core for insertion within the cell can. The timing sequence for core removal is presently under evaluation to avoid unraveling and distortion of the assembly during its removal. The feasibility of a syntron can loader which will interface with the core winder will be investigated so as to minimize handling of the completed core assembly

VII. ELECTROLYTE PREPARATION AND DISPENSING

The electrolyte dispensing valve and volumetric metering system design has been finalized and fabrication of component hardware has been initiated during this quarterly period.

The selected dispensing technique is essentially a volumetric system using a graduated syringe to meter a predetermined amount of electrolyte into the cell. The cell is fully evacuated and a specific amount of electrolyte is dispensed. Five to ten percent void space is allotted to permit thermal expansion of the electrolyte and prevent hydraulic pressurization. Cell weights are checked before and after fill to insure operation within an acceptable distribution curve. Normal electrolyte volume variations can be controlled to a minimum level with the proposed, technique; an important consideration with respect to small volume cells where minimum electrolyte tolerances are necessary to insure reproducible cell discharge performance.

The dispensing shuttle valve as illustrated in Figure 5 will sequentially operate under the following cycles:

- **BLOWOUT MODE**

  This cycle purges the line of residual electrolyte, contamination, etc.

- **VACUUM MODE**

  This cycle evacuates the cell to a predetermined level of vacuum.

- **ELECTROLYTE FILL MODE**

  This cycle dispenses a predetermined volumetric quantity of electrolyte into the cell.

- **CLOSED MODE**

  This is a stand-by cycle which permits loading and unloading of the cell assembly after blow out.

A three station dispensing system is currently proposed to attain the required production rate.

PCI is presently investigating the feasibility of incorporating automatic fill tube closure equipment into the dispensing station to permit hermetic closure immediately following the electrolyte dispensing cycle. Present plans call for the use of a pneumatically operated set of jaws which will pinch off the tantalum tube at a predetermined height.

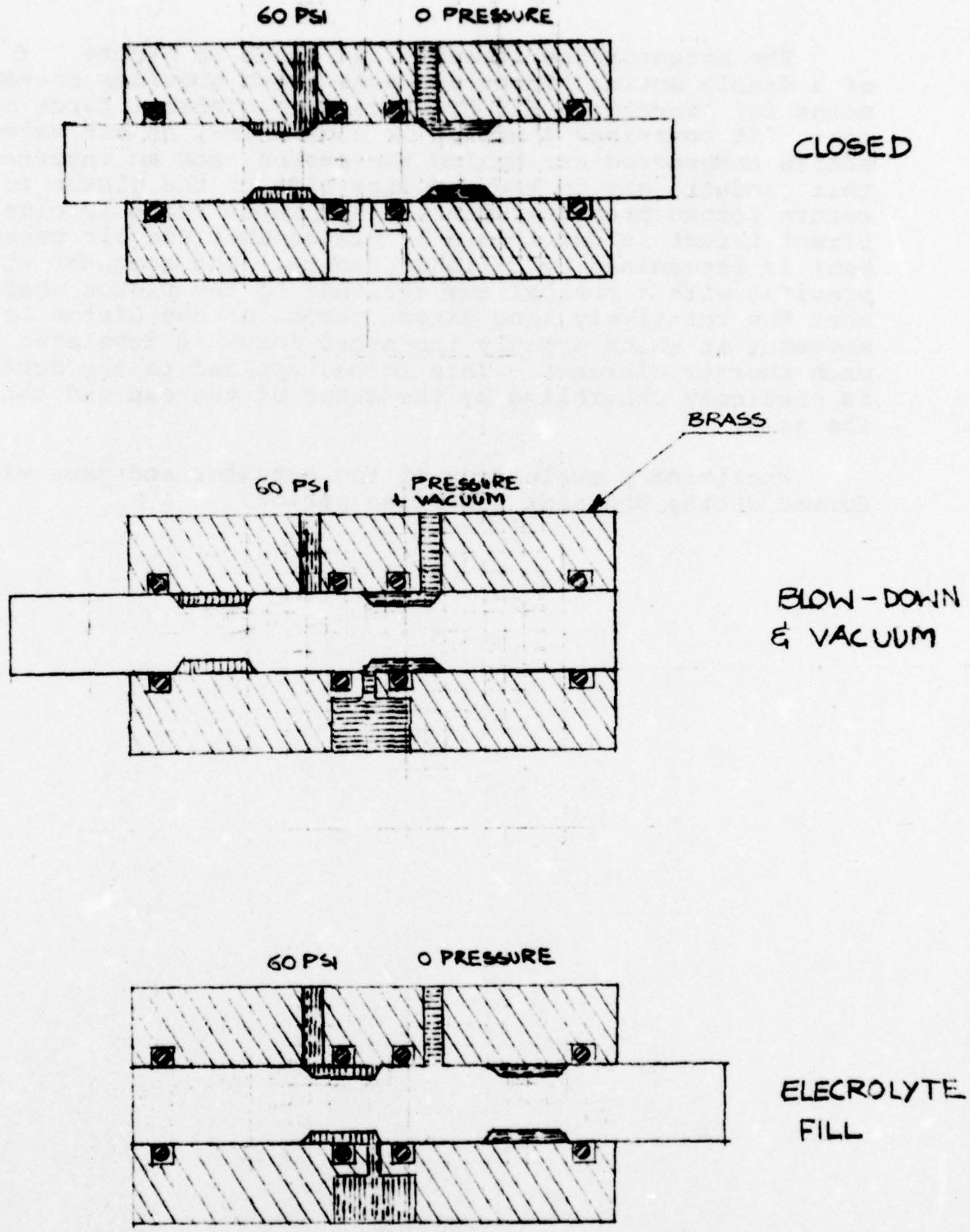
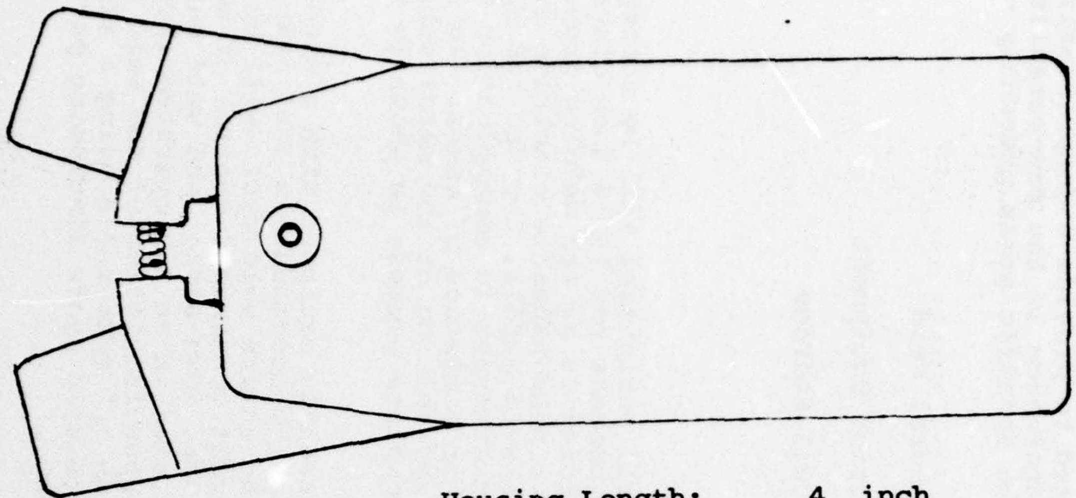

60 PSI
0 PRESSURE
CLOSED
BRASS
60 PSI
PRESSURE & VACUUM
BLOW-DOWN & VACUUM
60 PSI
0 PRESSURE
ELECROLYTE FILL

FIGURE 5

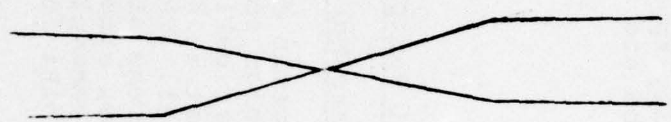
The actuator/jaw assembly, as shown in Figure 6 , consists of a double acting linear actuator which provides convenient means for converting air pressure to mechanical force and movement. It comprises a piston in a cylinder, an air valve that admits compressed air behind the piston, and an internal system that conducts air to the opposite side of the piston to apply return stroke pressure when the air input valve is closed. Direct thrust is determined by piston area and air pressure; movement is determined by cylinder length. The actuator will be provided with a conical cam attached to the piston shaft to convert the relatively long direct stroke of the piston to angular movement in which greatly increased force is developed through a much shorter distance. This force, applied to the cutting jaws, is precisely controlled by the shape of the can and the design of the jaws.

Preliminary evaluation of the actuator and jaws will be performed during the next reporting period.

TUBE CLOSURE JAWS



Housing Length:	4 inch
Overall Length:	5 inch
Maximum Opening:	¼ inch
Cutting Edge Width:	3/4 inch



CENTER CUT

FIGURE 6

VIII. HERMETIC SEAL AND CELL CLOSURE

During the third quarterly period, significant effort has been directed toward selection and initial fabrication of the hermetic closure equipment which will be used to meet the required hardware production levels. Selection of leak detection equipment has also been completed to provide a comprehensive in-process system for insuring conformance to the pre-established hermeticity specifications. The specific areas presently under evaluation are as follows:

- Cell Peripheral Weld
- Leak Detection Equipment
- Hermetic Cell Storage

A. Cell Peripheral Weld

1. Arc Welding

Hermetic closure of the cell peripheral will be accomplished using a high speed arc welding process for 15/16 inch diameter and larger cell sizes. TIG welding is an arc welding process by which heat is produced between a nonconsumable electrode and the work metal. The electrode, the weld puddle, the arc and adjacent heated areas are protected from atmospheric contamination by a continuous stream of inert gas or a mixture of gases. An hermetic weld is accomplished by localized melting of the metal substrate at the joint interface. The complete process is shown in Figure 7.

The arc weld system is presently equipped with a single weld torch head but has been designed to accomodate a dual station to permit welding of 5,000 units/day. The entire weld cycle will be fully automatic and programmed to permit continuous control of weld speed, torch retraction, up-slope, down-slope, and weld current. The cell will be vertically mounted in an air operated three jaw chuck which will be activated upon initiation of the weld sequence. Demonstration tests conducted on "D" size cells using a single torch head have shown a complete weld cycle (including part loading and unloading) of 9 seconds.

The basic arc weld system consists of the following modular components:

Power Supply

0.5 - 300 amp selenium rectified power supply to pro-

ARC WELDING

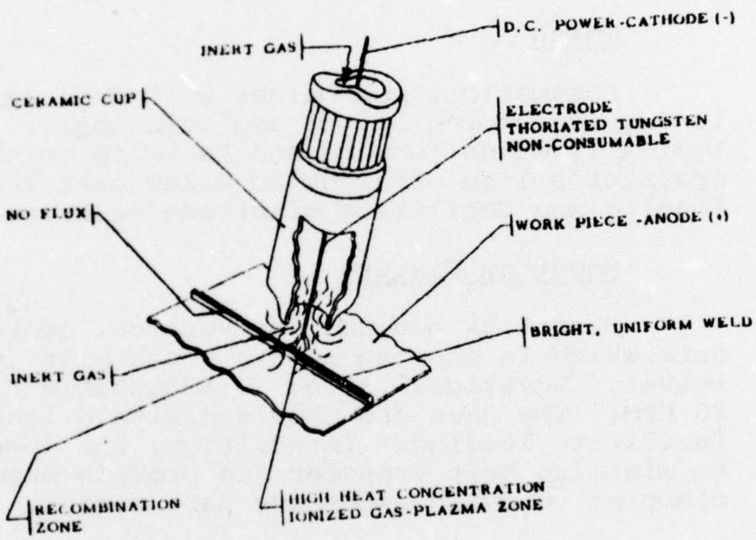


FIG. 7

vide a highly stabilized DC current for peak operating efficiency and maximum arc stability. Four overlapping current ranges of .5/8, 3/35, 20/175 and 125/300 amperes are available to provide adequate resolution over a wide operating range. Arc starting is accomplished by stabilized high frequency current which automatically terminates as soon as the arc is initiated.

Programmer

Three stage solid state weld programmer module to provide three time amperage cycles. This unit regulates the pre-established weld current during up-slope, weld cycle and down slope sequence. Dual flowmeters provide continuous control of the argon/hydrogen shielding gas with timed pre-flow for better arc starts and timed post flow for electrode and workpiece protection.

Torch

Pneumatic torch holder with dual axis positioner to regulate torch height and weld angle. The holder typically moves forward and backward in the plane of the operator's line of sight to allow cell loading and unloading and facilitate electrode maintenance as required.

Mounting Fixture

Headstock mounted for vertical centerline rotation onto which is mounted an air chuck with .040 inch jaw travel. Rotational speed is adjustable from 3 RPM to 26 RPM. The jaws are provided with a lead in taper to facilitate loading. In addition, the jaws are pointed to minimize heat transfer and provide precise centerline clamping to avoid excessive part runout.

Preliminary evaluation tests have been conducted on "D" cells to quantitatively determine the operating weld parameters. In addition, the optimal electrode characteristics and shield gas compositions have been defined as follows:

a. Electrode Design - 2% thoriated tungsten electrodes have been selected for the peripheral arc weld. The electrode diameter used under the pre-established weld current profile was established at 1/16 inch for the "D" cell. At any given amperage, the electrode top will become hotter as the electrode diameter is decreased. The

ideal condition is to adjust the diameter to bring the top temperature just below its melting point, since electron emission is at its peak at this temperature.

b. <u>Electrode Contamination</u> - There are three broad types of electrode contamination which must be minimized during production welding:

. Oxidation due to improper gas post flow or improper gas coverage during welding.

. Metallization due to vaporization of the workpiece.

. Splatter caused by eruptions created by gas entrapment, oil, moisture or other surface impurities.

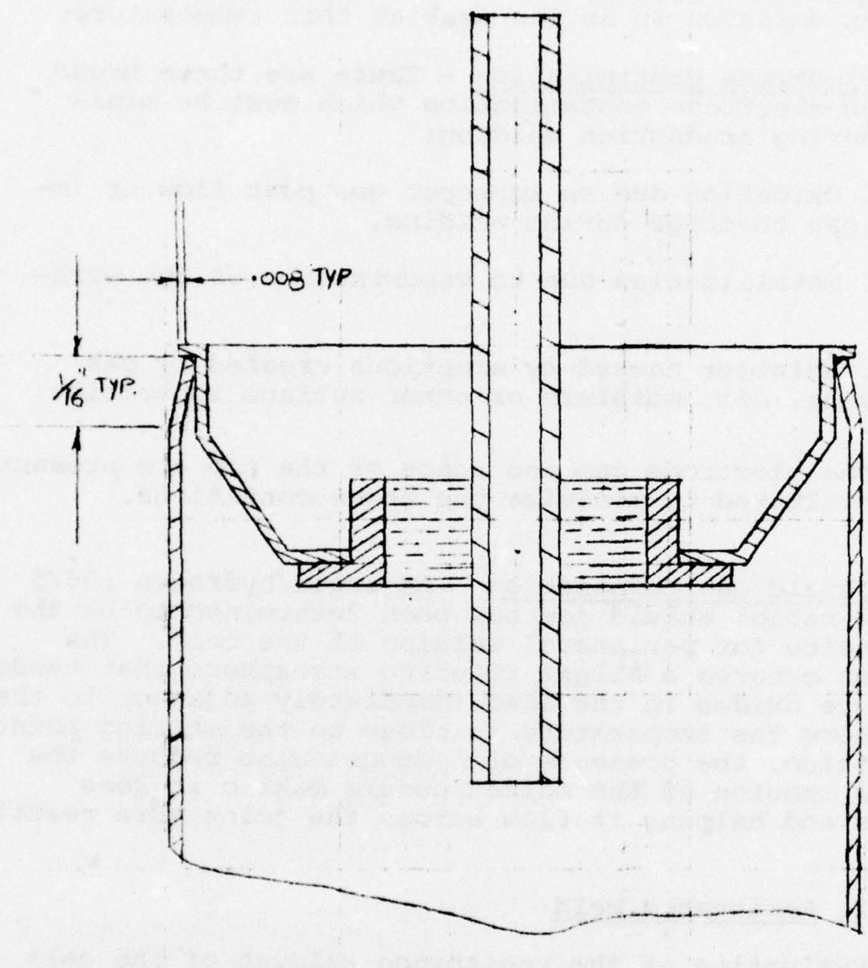
The electrode gap and shape of the tip are presently being evaluated to minimize the above conditions.

c. <u>Shield Gas Composition</u> - An argon/hydrogen (95/5 or 98/2 ratio) shield gas has been determined to be the best choice for peripheral welding of the cell. The hydrogen creates a slight reducing atmosphere that tends to remove oxides in the area immediately adjacent to the weld where the temperature is close to the melting point. In addition, the presence of hydrogen also reduces the surface tension of the molten puddle making it less viscous and helping it flow across the joint more readily.

2. <u>Resistance Weld</u>

Evaluation of the resistance welding of the cell periphery on small diameter cells has continued during this quarterly period in an effort to finalize welder specifications and operating parameters. The present weld configuration as shown in Figure 8 utilizes the blunt can edge formed during the clip-off operation. This edge is subsequently rolled inward to minimize contact surface area. Difficulty in achieving reproducible hermetic welds has been due to the following:

. Rolling of the can edge must be closely controlled to avoid surface contact along the vertical wall of the top shell. Contact surface area must be minimal to avoid heat unbalance characteristics and non-uniform weld nuggets.



RESISTANCE WELD
CAN/ TOP SHELL CONFIGURATION

FIGURE 8

. Electroless nickel plating thickness of the can and top shell must be properly controlled to avoid weld arcing yet provide a surface free of oxidation. Optimal plating thickness is considered to be 100 $\pm$ 50 micro-inch. Parts fabricated from pre-plated material were found to be unsatisfactory due to the presence of a copper flash under the nickel substrate; a configuration normally used to strengthen adherence of the nickel plate. Such a condition is not suitable for resistance welding due to its high electrical conductivity.

. The configuration of the upper and lower electrodes must be designed to achieve a stable heat balance during the weld cycle. An unbalanced heat condition at the weld interface will result in a poor structural weld and excessive part deformation. Various electrode and part configurations are presently under evaluation to determine the optimal condition.

B. Fill Tube Closure

Embrittlement of the tantalum fill tube during hermetic closure has been experienced due to inadequate control of the processes used during tube fabrication and again during glass seal fabrication. Tantalum must be contained within an inert or vacuum atmosphere during exposure to high thermal processes to prevent surface contamination and subsequent embrittlement of the metal. A ductility test has been incorporated into the glass/metal seal specification to quantitatively determine the level of embrittlement both after tube fabrication and immediately following glass seal manufacture. Such measurements will insure the structural integrity of the fill tube and minimize seal problems previously encountered during hermetic closure.

C. Leak Detection Equipment

An automated helium mass spectrometer (Varian Model 936-70) has been ordered to permit in-process leak detection surveillance on the following:

. Glass/Metal Seal Assembly

. Seal/Top Assembly

. Top/Can Peripheral Weld

. Fill Tube Closure

The leak detector is equipped to operate under both gross and fine leak test modes with a maximum cycle time of six seconds. Equipment sensitivity is rated at 4 x 10^{-10} atm. cc/sec helium. The unit is equipped with a built-in calibrated leak standard to permit periodic in-process machine calibration.

The leak detector design is based on a technique which utilizes the differences in maximum pressure ratios produced by the diffusion pump for gases of different molecular weights. This principle, as illustrated in Figure 9 is implemented by introducing helium (and other inlet gases such as those resulting from a leak in the test piece) into the diffusion pump foreline rather than into the "normal" pump inlet as in conventional leak detectors. Helium, having a much lower maximum pressure ratio than other gases contained in air, diffuses backwards through the diffusion pump to reach the spectrometer tube where it is detected as a leak in the normal manner. Although the mechanical pump is also attached to the diffusion pump foreline and removes all inlet gases, including helium, there is no appreciable loss of sensitivity in the 936-70 Leak Detector.

By optimizing the maximum pressure ratio between helium and the other gases of heavier molecular weights, the diffusion pump becomes a trap that filters out the other gases and contamination, such as water vapor, introduced by the connection of the test piece to the leak detector. This eliminates the need for any cryogenic trapping.

A diffusion pump used in this fashion also acts as a buffer that protects the spectrometer tube from pressure bursts that would normally endanger the mass spectrometer tube and trigger protective devices. Interruption of testing due to pressure bursts is less frequent, and the unit can be used at higher pressures up to approximately 500 millitorr, allowing the measurement of gross leaks without the need for special throttling devices or special test techniques.

The maximum pressure ratio of helium to other gases normally found in a leak detector can be varied by changing the pump action of the diffusion pump. A control is provided to allow the variation of this pressure ratio and thus increase or decrease the sensitivity of the leak detector as required by the application.

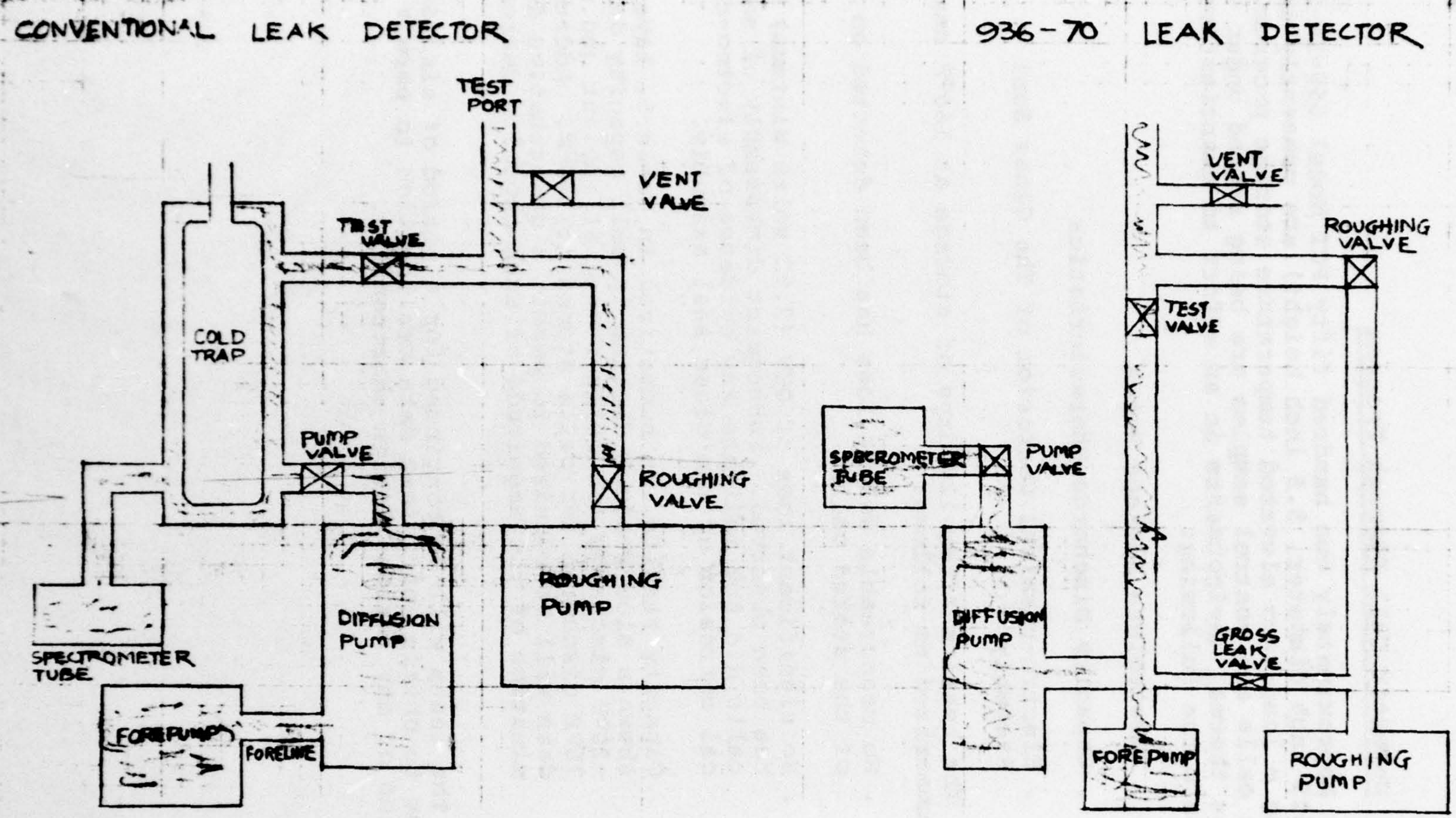


FIGURE 9

HELIUM MASS SPECTROMETER

D. <u>Hermetic Cell Storage Program</u>

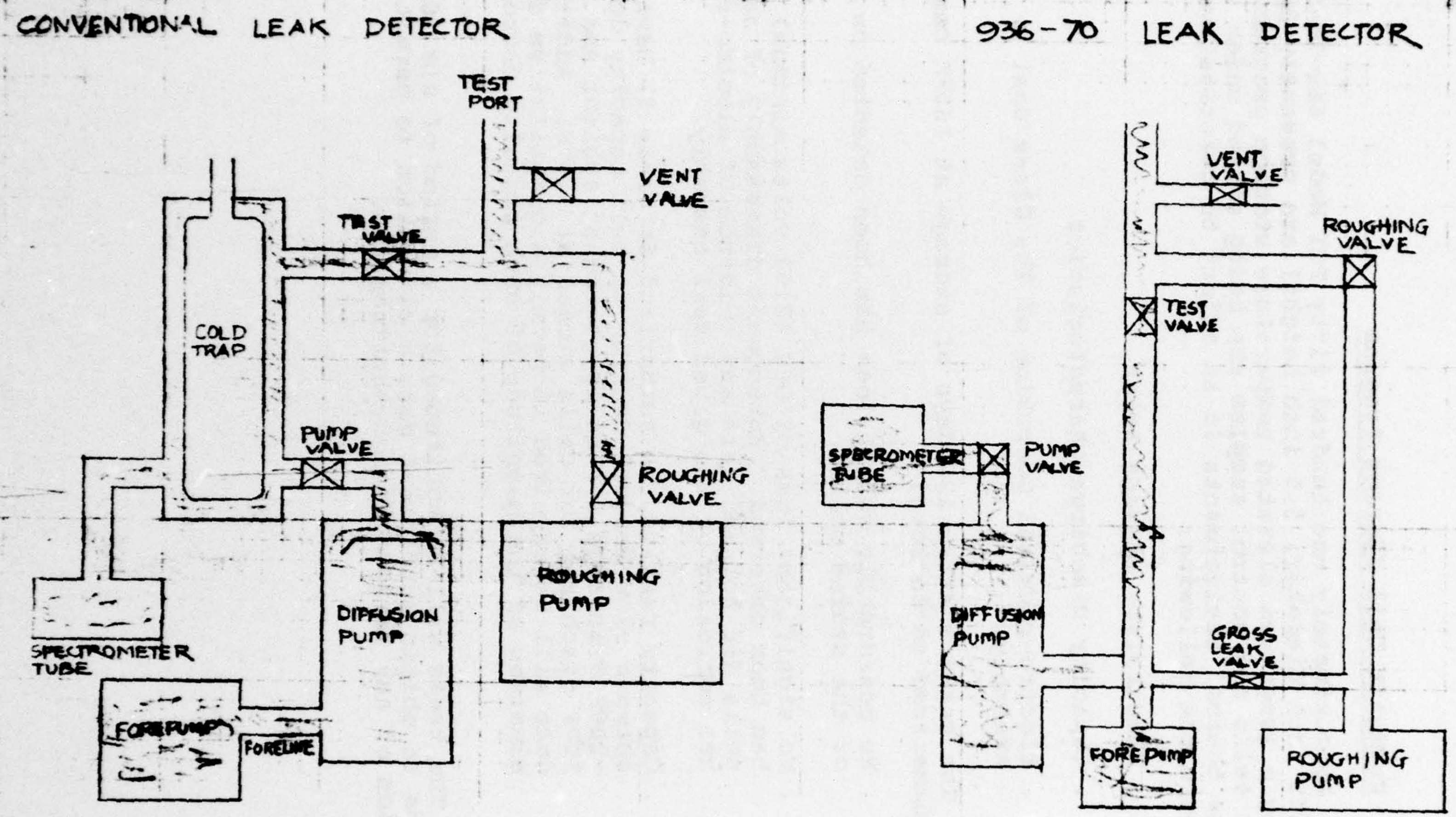
Approximately one hundred fifty PCI Model 660-5A-S (1.625 inch diameter, 5.5 inch height) are presently undergoing a long-term elevated temperature storage program. Both test cells and control samples are being stored under various thermal environments in an effort to quantitatively measure the following:

- Electrolyte Leakage Rates
- Capacity Discharge Characteristics
- Electro-chemical Corrosion of The Glass Seal Assembly

The results after 120 days of storage at 160°F can be summarized as follows:

- No measureable weight loss has been detected on any of the stored cells.
- No significant loss of OCV (2.92 volts minimum) has been observed. Subsequent disassembly of sample cells did not indicate any evidence of electro-chemical corrosion of the glass seal assembly.
- Capacity results, as summarized in Table 5, have shown a slow gradual decline in cell capacity during -20°F discharge for cells stored at ambient and during 70°F discharge for cells stored at 160°F. Additional data will be required to permit a quantitative determination of the magnitude of such capacity decreases.

The tests will be continued for a period of six (6) months to obtain sufficient data verification to permit detection of any serious design shortcomings.



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HELIUM MASS SPECTROMETER

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TABLE 5

HERMETIC CELL STORAGE PROGRAM

CAPACITY DATA SUMMARY

LOAD 1.9 OHMS

STORAGE DAYS @ ROOM TEMPERATURE	0	30	60	90	120
AVERAGE SERVICE HOURS @ 2.0 VOLTS					
$+70^{0}F$	17.5	16.1	18.2	18.2	18.2
$-20^{0}F$	9.7	9.1	8.9	8.8	8.5
STORAGE DAYS @ $160^{0}F$	0	30	60	90	120
AVERAGE SERVICE HOURS @ 2.0 VOLTS					
$+70^{0}F$	17.5	15.8	14.8	14.8	13.8
$-20^{0}F$	9.7	10.2	11.5	9.6	11.4

IX. CONCLUSIONS

During the present quarterly period, effort has continued in accordance with the planned engineering objectives as defined in the PERT/TIME Network. These objectives include the fabrication and preliminary evaluation of the production equipment and the fabrication and evaluation of hermetic cell assemblies and components. Several areas of difficulty experienced during the hermetic cell/battery fabrication process and equipment evaluation are currently being resolved to permit design finalization. The cumulative effect of these problems will be reviewed during the next quarterly period to determine their impact on the scheduled milestones defined in the PERT/TIME Network.

Fabrication difficulties experienced during the construction of initial cell/battery prototypes has necessitated the following corrective action:

. Modification of the vent design configuration for the BA-5100/BA-5090 cells to prevent distortion of the can periphery.

. Continued evaluation will be required to accomplish the peripheral weld of BA-5574/BA-5841/BA5090 cells to prevent thermal cracking of the glass/metal seal. Such evaluations will include resistance welding techniques and arc welding using the production system.

. Re-design of the BA-5567/BA-5568 cell to minimize electrode registration problems and increase internal cell volume.

Preliminary discharge tests on the BA-5590, BA-5598, and BA-5842 hermetic cells have been performed. Results indicate that all capacity requirements will be achieved.

The side wall vent design will be incorporated on all cell types required under this program. Abuse tests will be continued during the next reporting period to further define the vent operating parameters on various size cells.

Re-design of the anode machine is required to incorporate a transfer feed and storage mechanism which would mate with the input of the core winder. Automatic transfer and storage

of the tabbed anode assemblies is required to minimize distortion and sticking of the lithium. Component fabrication is scheduled for the next reporting period.

The semi-automatic core winder has been installed at PCI and is presently undergoing evaluation. Electrode flatness and alignment must be accurately controlled to permit rapid loading and transfer within the core winder. PCI is investigating the use of tapered feeder slits and the incorporation of a semi-automatic rolling/feeding mechanism to minimize material handling.

Prototype cathodes have been fabricated and evaluated to quantitatively determine the operating parameters of the continuous cathode machine. *Preliminary discharge tests indicate* equivalent or superior performance under various load profiles. automatic mixing equipment will be required in order to accurately define such parameters as the optimal carbon/teflon/water ratio, slurry viscosity and to insure homogeneity of the raw mix. Effort must be directed on the slitting and storage of cathodes to minimize material handling and insure electrode flatness.

Volumetric dispensing of the electrolyte is the technique selected for accomplishing electrolyte fill. Pneumatically operated jaws will be incorporated into the dispensing station to permit uniform tube closure to predetermined height specifications.

The arc welding process has been selected for peripheral welding of 15/16 inch diameter and larger cell sizes. Demonstration tests conducted on "D" size cells indicate a total cycle time of 9 seconds per cell. Use of a dual head station will permit attainment of the required 5000 units/day production objective. Continued evaluation of the resistance weld technique on small diameter cells will be required to quantitatively determine the proper roll-over angle, plating specification and electrode configuration. A helium mass spectrometer is presently being procured to permit in-process leak detection surveillance on the glass/metal seal, seal/top assembly, top/can peripheral weld and fill tube closure.

X. PROGRAM FOR 4th QUARTER

The proposed program for the next reporting period will include the following:

- Continued fabrication and evaluation of hermetic cell assemblies and review of equipment fabrication status.
- Selection of peripheral resistance weld equipment and fabrication of required tooling and fixtures.
- Continued evaluation and analysis of the side wall safety vent mechanism on all cell sizes.
- Completion of cell/battery drawing packages and process specifications
- Construction of engineering sample prototype batteries.

XI. IDENTIFICATION OF PERSONNEL

The following additional personnel are presently involved in the subject program:

Ralph Mantello

Mr. Mantello has over thirty years experience in the areas of automation equipment design, development and tooling used in the manufacture of silver-zinc, silver-cadmium and zinc-air fuel cell battery systems. He is presently responsible for the development of automatic manufacturing process techniques and the implementation of such equipment used in the fabrication of lithium cells and batteries.

Stanley G. Lewin

Mr. Lewin has nearly twenty years experience in manufacturing,engineering and operations management of precision wire-wound resistors, electronic networks and battery powered survival equipment for both commercial and military applications. His experience encompasses the areas of such assembly techniques as injection molding, soldering, riveting, ultrasonic welding/brazing, encapsulation procedures and packaging. He is presently responsible for production scheduling and supervision, implementation of automated production equipment and general management of plant operations.

The labor hours expended during this quarterly reporting period are as follows:

Dr. Stewart M. Chodosh Contracts Administrator and Program Manager	55 hrs.
Martin G. Rosansky Senior Engineer	425 hrs.
Thomas M. Watson Senior Engineer	436 hrs.
Anandaram Joshi Test Engineer	78 hrs.
Julius Cirin Technician	233 hrs.
Ralph Mantello Technician	372 hrs.
James Harris Technician	210 hrs.
Prakash Jog Engineer	70 hrs.
Stanley Lewin Operations Manager	102 hrs.

XII PUBLICATIONS AND REPORTS

No publications or reports were issued during this quarterly period.

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